

S
551.5
Hama
1979
Vol. 1

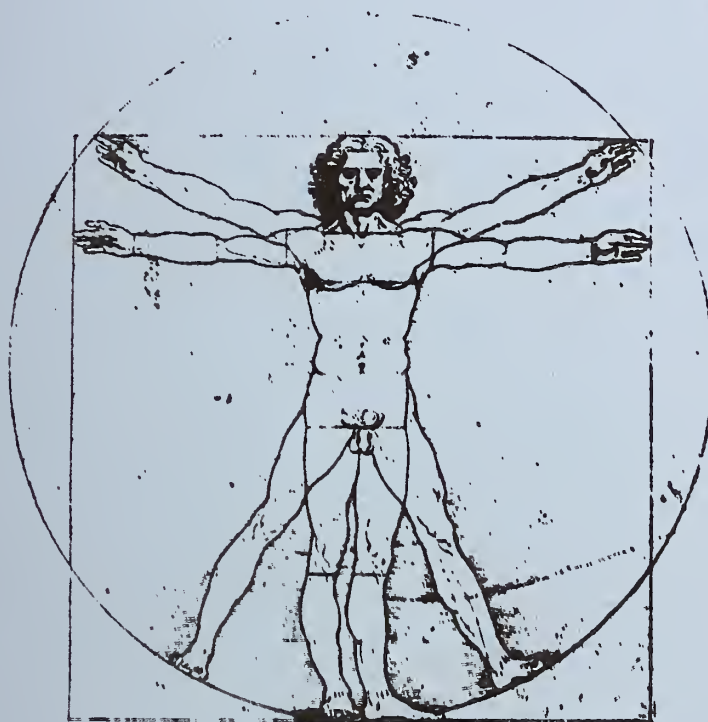
PLEASE RETURN MONTANA AIR POLLUTION STUDY

**Meteorological Summary — First Year
July, 1979**

STATE DOCUMENTS COLLECTION

AUG 29 1979

MONTANA STATE LIBRARY
930 E Lyndale Ave.
Helena, Montana 59601



AIR QUALITY BUREAU
ENVIRONMENTAL SCIENCES DIVISION
DEPARTMENT OF HEALTH & ENVIRONMENTAL SCIENCES
HELENA, MONTANA 59601

~~DATE~~ OCT 31 '79

~~DATE~~ JUL 23 '80

AUG 30

MONTANA STATE LIBRARY

S 551.5 H2ma c.1

Montana air pollution study : meteorologi



3 0864 00035224 8

MONTANA AIR POLLUTION STUDY
Meteorological Study - First Year

Authors

James W. Gelhaus, Air Pollution Meteorologist
Air Quality Bureau
Montana Department of Health and
Environmental Sciences
Project Officer, Meteorology and
Modeling Studies

William Campbell, Independent Meteorologist
Field Meteorologist for Kalispell/Columbia
Falls Area Meteorology Studies for MAPS

Steven Harner, Independent Meteorologist
Field Meteorologist for Anaconda/Butte
Area Meteorology Studies for MAPS

Michael Machler, Independent Meteorologist
MAPS Main Office Meteorologist in charge
of Data Analysis

Terri Middlemist, Independent Meteorologist
Field Meteorologist for Missoula Area
Meteorology Studies under MAPS

Aaron L. Zimmerman, Certified Consulting
Meteorologist, Field Meteorologist in
charge of Field Operations of Meteorology
Studies for MAPS

Michael D. Roach, Chief, Air Quality Bureau
Montana Department of Health and Environmental
Sciences
Project Manager of MAPS

PREFACE

This document is one of a series of technical reports presenting results from the Montana Air Pollution Study (MAPS), a special air monitoring and health effects project of the Air Quality Bureau of the Montana Department of Health and Environmental Sciences. The MAPS program was funded by the 1977 Montana Legislature with \$1.07 million for the 1977-79 biennium in order to develop an improved understanding of the effects of air pollution on health in Montana.

The various activities undertaken as part of the MAPS effort have been grouped into five major categories for purposes of project management: Health Effects, Air Quality, Meteorology/Modeling, Emission Inventory, and Statistics and Data Systems. Each of these technical areas is presenting results in one or more technical reports prepared by the personnel directly involved in the study efforts. In addition, an overall technical summary report and a less technical report to the public will be prepared.

This specific report, in the Meteorology/Modeling area, presents results of the first year of the surface and upper air meteorological monitoring. The study was designed and coordinated by James Gelhaus, Air Pollution Meteorologist of the Air Quality Bureau. Individual sections of the report were written by field or office meteorologists and edited by Mr. Gelhaus.



Digitized by the Internet Archive
in 2013

http://archive.org/details/montanaairpollut1979mont_0

EXECUTIVE SUMMARY

This report provides a summary of the first year of data on surface and upper air meteorology as related to air pollution potential. The Montana Air Pollution Study established major meteorological monitoring sites in Billings, Butte, and Missoula; also included is similar data gathered in Anaconda and Kalispell under other, coordinated Bureau projects.

Primary parameters measured were surface and upper level wind speed and direction; inversion height, thickness and strength; stability; and visibility. Various other meteorological parameters were also measured or gathered from other data sources such as the National Weather Service, companies, or institutions.

This report is a summary of the sampling program and discussion of results obtained during the first year of the study. The sampling period covered is May 1978 through April 1979. This report does not include the actual data summaries or raw data. The data is included in a separate volume as an appendix.

Data on the surface and upper level winds in the various study areas has revealed predominant wind patterns for the various months and seasons sampled. Inversion data from two measurement methods has also been summarized, and comparisons made as to frequency of occurrence of various inversion parameters such as thickness, height, intensity, and duration. Stability data derived from acoustic radar data, cloud data, and wind speed has also been tabulated continuously in two-hour periods. Discussions relate mainly to the climatology

of the various study areas as related to air pollution potential. Conclusions regarding pollution levels and their relation to air pollution sources are not attempted in this report.

TABLE OF CONTENTS

	<u>Page</u>
EXECUTIVE SUMMARY	i
I. INTRODUCTION	1
II. STUDY DESIGN AND METHODOLOGY	3
MEASUREMENT METHODS	3
SITE DESCRIPTIONS	7
III. DISCUSSION OF RESULTS	14
ANACONDA	14
BILLINGS	26
BUTTE	33
MISSOULA	41
KALISPELL	53
IV. SUMMARY	66
REFERENCES	67

LIST OF TABLES

<u>No.</u>	<u>Description</u>	<u>Page</u>
1	Summary of Meteorological Monitoring Network	5
2	Ambient Air Network Site Locations	6
3	Holzworth Lapse Rate Categories (Modified)	21
4	Average Monthly Mixing Heights (Missoula)	47

I. INTRODUCTION

Meteorological conditions have a major effect on the frequency and severity of air pollution concentrations in the air. The ability of the lower atmosphere to disperse, dilute and mix pollutants released into it can vary immensely with meteorological fluctuations from day to day, week to week, and season to season. These meteorological variations are a major influence on air pollution concentrations. Therefore, it is essential that such meteorological variations be measured and compared with the associated changes in pollution to determine their relationship. Only through the analysis of air quality and meteorology together is it possible to describe, anticipate, or predict accurately the ambient pollution concentrations.

The lower atmosphere air movement patterns typical of the mountainous terrain of the western part of the country are far more erratic than those over flat terrain. Valley-mountain terrain causes air movement patterns that frequently vary greatly over short distances. Several Montana cities are located in valleys surrounded by mountains. In these areas, the escape of pollutants from the valley "bowl" is very limited under certain meteorological conditions, such as low winds and temperature inversions.

The meteorological network established in Montana in the past, primarily by the National Weather Service, has provided a basis for

describing or forecasting the general weather conditions that apply to large areas, usually the size of several counties. The major forecast emphasis has been on temperature and precipitation and the occurrence of storms accompanied by high winds, blizzards, flooding, and other such phenomena. This data network is not adequate to provide data needed to identify and to understand local meteorological effects on air pollution.

One of the objectives then of the Montana Air Pollution Study (MAPS) was to better define the primary meteorological parameters that affect air pollution levels in the various study areas.

In the planning of MAPS, several technical advisory committees were established to review the data needs and make recommendations on the project design. The MAPS Advisory Committee for Meteorology/Modeling reviewed the present data sources in the study areas and compared these sources with the data needs. Priorities were then assigned to determine which meteorological parameters should be measured initially to better describe each area. The MAPS staff, following the recommendations of the advisory committee, implemented a network of meteorological monitors to provide data needed to identify and to understand meteorological effects on air pollution in each study area.

II. STUDY DESIGN AND METHODOLOGY

The following describes generally the MAPS meteorological measurement methods and sampling sites determined to be essential in evaluating the inter-relationship between meteorology and air quality. Table 1 provides a listing of the meteorological parameters collected under MAPS and other studies being conducted at the same time. The parameters listed were adopted during discussions of the MAPS Advisory Committee on Meteorology and Modeling.

Wind speed and wind direction were measured at the surface by anemometers mounted on ten meter towers at the MAPS sites. The strip charts were reduced to provide hourly averages of wind direction, wind speed, wind range and peak wind gust. Other data were collected from various companies and the National Weather Service (NWS).

Solar radiation instruments measuring the amount of total radiation over the broadband were operated in four of the study areas. Hourly average values of solar insolation were reduced from the strip charts.

Measurements of the amount of turbidity in the atmosphere were made at six areas of Montana during the study period. The turbidity measurements are related to the amount of fine particulates or dust suspended in the atmosphere as well as water vapor and other gaseous compounds. Measurements were taken when the sun was unobscured by clouds at 0900, 1200 and 1500 Mountain Standard Time (MST).

Temperature, dewpoint, and pressure were measured at the major MAPS sites and reduced to hourly averages. Data was also obtained from companies and the National Weather Service (NWS) on temperature, relative humidity, and pressure. The NWS also provided information on cloud cover and precipitation.

Upper air data on wind speed, wind direction, and temperature lapse rate (temperature change with height above ground) were measured at one or more locations at the four study areas. Measurements were made using meteorological balloons (pilot balloons) and temperature sensors which were released and tracked vertically to heights of at least 7000 feet above ground level (weather permitting). Balloons were released three days a week at one-half hour after sunrise and again at 1400 MST (Gelhaus, 1979a).

Upper air information was also obtained from the use of acoustic radars. The acoustic radar works on the principle of transmitting a sound pulse vertically in the atmosphere, and by measuring the amount and intensity of sound reflected back, information was obtained continuously on stability, inversion heights and mixing heights (Gelhaus, 1979b).

TABLE 1

SUMMARY OF METEOROLOGICAL MONITORING NETWORK

<u>Parameter</u>	<u>Anaconda</u>	<u>Billings</u>	<u>Butte</u>	<u>Missoula</u>	<u>Kalispell</u>
Wind speed and direction	Lincoln School Highway 48 Junction Anaconda Co. (6)	Central Park NWS-Airport	Hebgen Park FAA-Airport "Alpine West" MHD facility	Lions Park Stiegler Site Olofson Site University Park Hoerner-Waldorf NWS-Airport	Columbia Falls Polson Kalispell-Airport NWS-Airport
Solar radiation	Lincoln School	Central Park	Hebgen Park MHD facility	Lions Park	Kalispell-Airport
Turbidity	Lincoln School	Yellowstone County APC Office	Hebgen Park	Nursing School	Columbia Falls
Temperature	Lincoln School Anaconda Co. (2)	Central Park NWS-Airport	Hebgen Park FAA-Airport MHD facility	Lions Park NWS-Airport	Kalispell-Airport
Relative humidity or dewpoint	Lincoln School Anaconda Co.	Central Park NWS-Airport	Hebgen Park FAA-Airport MHD facility	Lions Park NWS-Airport	Kalispell-Airport NWS-Airport
Barometric pressure	Lincoln School Anaconda Co.	Central Park NWS-Airport	Hebgen Park FAA-Airport MHD facility	Lions Park NWS-Airport	NWS-Airport
Stability and inversion height	Highway 48 Junction	Vo-Tech site	MHD facility Airport site	USFS Fire Lab	Kalispell-Airport
Upper level wind	Highway 48 Junction	Vo-Tech site	Airport site	USFS Fire Lab	Kalispell-Airport
Precipitation	Anaconda Co.	NWS-Airport	FAA-Airport	NWS-Airport	NWS-Airport
Cloud cover and height		NWS-Airport	FAA-Airport	NWS-Airport	NWS-Airport

TABLE 2
 AMBIENT AIR NETWORK SITE LOCATIONS

<u>City</u>	<u>Site Name</u>	<u>Location</u>
Anaconda	Highway Junction	2 mi. NE of Anaconda Co. Smelter
	Lincoln School	2 mi. WNW of Anaconda Co. Smelter in Anaconda
	Anaconda Co. #1	2 mi. NW of Anaconda Co. Smelter
	Anaconda Co. #2	3.5 mi. ENE of Anaconda Co. Smelter
	Anaconda Co. #4	2 mi. SW of Anaconda Co. Smelter
	Anaconda Co. #5	0.75 mi. SSW of Anaconda Co. Smelter
	Anaconda Co. #6	2 mi. W of Anaconda Co. Smelter
	Anaconda Co. #7	1.25 mi. NNW of Anaconda Co. Smelter
Billings	Vo-Tech	1 mi. W of Billings
	Central Park	1 mi. W of downtown Billings
	National Weather Service	N. of Billings above rimrocks
	Laurel Farm Yellowstone County Air Pollution Control Office	0.5 mi. S of Laurel Downtown Billings
Butte	Hebgen Park	In Butte, 2 mi. SSW of Berkely Pit
	Butte Airport (FAA)	S. of Butte in valley floor
	MERDI	S. of Butte in valley floor
	Butte-Silver Bow County Health Dept.	Downtown Butte
	Glacier Park International Airport (NWS)	8 mi. NNW of Kalispell
Kalispell/Columbia Falls	Polebridge	Polebridge
	Polson	Polson
	Teakettle Mountain	2 mi. NE of Columbia Falls
		SE of Downtown Missoula
Missoula	Lions Park	6 mi. W of Missoula
	Johnson Bell Airport (NWS)	2 mi. SW of Missoula
	Olofson	7 mi. WNW of Missoula
	Stiegler	University of Montana
	University	10 mi. NW of Missoula
	Hoerner Waldorf #1	KECI TV Tower 10 mi. N of Missoula 700 ft. above Missoula Valley
	TV Mountain	0.5 mi. W of downtown Missoula
	MAPS office	7 mi. NW of Missoula
	U.S. Forest Service (Fire Lab)	

Site Descriptions

The following discussion describes the various sites used in the MAPS and other studies data of which was used in this report. A summary listing of the sites and the meteorological parameters obtained at each site is given in Table 1. A description of the site locations is given in Table 2.

Anaconda

The study area is situated at the southwest corner of a large mountain-highland (Deer Lodge Valley). The valley provides the headwaters for the Clark Fork River. The area experiences frequent nocturnal and climatic temperature inversions. It also experiences unique wind conditions due to the terrain's influence on predominant winds and the various mesoscale drainage systems.

The Highway Junction site is located two miles northeast of the Anaconda Company smelter works in a relatively obstruction-free area. The site provides a continuous record of surface wind speed and wind direction, inversion and mixing heights, and upper level wind information.

The Lincoln School site is located two miles northwest of the smelter in Anaconda. It is situated in the northwest corner of the Lincoln School playground. The site contains systems to record continuously surface wind speed, wind direction, temperature, dewpoint, solar radiation, visual range and pressure.

The Anaconda Company ambient air network provides surface meteorological data from six stations at various locations in the area. All data is put into The Anaconda Company central computer for processing and printout. The data is then sent to the Air Quality Bureau in Helena.

Billings

The study area is the Yellowstone River Valley, located in south-central Montana. The valley, elevation 3100-3600 feet MSL, is situated on the border line area between the Great Plains and the Rocky Mountains. The immediate Billings area is prone to air stagnation problems due to the cliffs or rimrocks enclosing much of the metropolitan area. Inversions and slow wind speeds trap air pollutants in the area below the cliffs for extended periods of time.

The Central Park site is located one mile west of downtown Billings. The site is equipped to monitor continuously surface wind speed, wind direction, temperature, dewpoint, solar radiation, pressure and visual range.

Upper level wind speed and wind direction measurements are made at the Vocational, Technical and Career Placement Center (Vo-Tech) west of Billings. Located to the north and east of the Vo-Tech Center is a sparse residential area and to the south and west an agricultural area. The site also provided data on inversion heights, mixing heights and stability.

The National Climatic Center, Asheville, N.C., supplied the study with the surface observations for the Billings National Weather Service (NWS) station. The Billings NWS station, Logan Field International Airport, lies atop the rimrocks to the north of the city. The data included wind speed, wind direction, temperature, dewpoint temperature, pressure, solar radiation, precipitation, and cloud cover.

Surface wind speed and wind direction were recorded continuously at a site one-half mile east of the Laurel Cenex Refinery, and just south

of Interstate 90. The site is relatively obstruction free.

Turbidity measurements, using a sun photometer, were taken at the Yellowstone County Air Pollution Control Office, Second Avenue North, in Downtown Billings.

Butte

The study area is a relatively small (ten x five miles) mountain-highland valley in southwestern Montana. It is situated at an approximate elevation of 5500 feet adjacent (west of) the Continental Divide. The area experiences frequent inversion conditions especially long-lived and intense during the winter season. Due to its high elevation and the cold air pooling effect of the valley, it is also noted as an especially cold area.

The Hebgen Park site is located in central Butte on First Street, two miles south-southwest of the Berkeley open pit mine. The city of Butte lies at the northern perimeter of the valley. Surface wind speed and direction data were collected continuously by a wind system located atop the site's thirty foot tower. The site also provided data on upper level wind speed and direction.

The Butte Airport site is located at the south end of the Silver Bow County Airport's garage complex. The airport is located approximately in the center of the lower valley. The site was equipped to measure upper level wind speed and wind direction and temperature lapse rate.

The airport is also the site for the Federal Aviation Administration Flight Service Center. The surface observations taken are wind speed, wind direction, temperature, dewpoint temperature, precipitation, and cloud cover. Copies of the daily data were supplied to the Air Quality

Bureau and reduced to a computer format similar to the National Weather Service (NWS) Climatological cards received from Asheville, North Carolina for Billings, Kalispell and Missoula.

The Montana Energy Research and Development Institute (MERDI) provided meteorological data to the Air Quality Bureau. Such data dates back to February 1978. The data was collected from two sites, the Permanent Meteorological Station and the Paxson Station, both of which are located at the southern end of the valley. The Permanent Meteorological Station included a forty-meter (130 foot) tower that provided temperature at ten and forty meters (for lapse rate purposes), wind speed, wind direction and horizontal standard deviation of wind direction at ten and forty meters, dewpoint temperature at ten meters, and vertical standard deviation of wind speed and direction at forty meters. The station also provided solar radiation, precipitation, pressure, atmospheric stability and inversion information (by means of an acoustic radar system).

The Paxson Station provided surface temperature, dewpoint, wind speed, wind direction, precipitation, pressure and solar radiation. This data has been supplied to the Air Quality Bureau but has not yet been analyzed. Future reports will attempt to include this data.

Turbidity measurements, using a sun photometer, were taken in uptown Butte, at the Butte-Silver Bow County Health Department.

Columbia Falls/Kalispell

The study area is the Flathead Valley, approximately forty miles west of the Continental Divide. The area's climate is affected greatly by its close proximity to Flathead Lake and the surrounding high mountains.

Upper level wind and temperature measurements were made at Glacier

Park International Airport, approximately eight miles north-northwest of Kalispell under the Flathead Environmental Study. The site was also equipped to record continuously: surface wind speed, wind direction, temperature, dewpoint temperature, pressure visual range, stability and inversion information.

Surface meteorological data was obtained from the Kalispell National Weather Service (NWS) station at Glacier International Park Airport. The data consisted of: wind speed, wind direction, temperature, dewpoint temperature, pressure, solar radiation, precipitation and cloud cover. The Kalispell NWS station also provided a breakdown of hourly visibility into quadrants during daylight hours.

Surface wind speed, wind direction and temperature were measured continuously near the Polebridge Ranger Station. Due to the closeness of large trees and buildings at the ranger station which could affect the local wind speed and direction, the equipment was moved to a large open meadow two miles north of the Ranger Station (Big Prairie).

Surface wind speed, wind direction, temperature, and solar radiation were recorded continuously at the Big Sky Stables in Polson. The site is relatively free of trees or buildings which could affect wind flow.

At a site one mile north of the Anaconda Aluminum Plant in Columbia Falls, surface wind speed, wind direction, temperature and solar radiation were recorded continuously.

Turbidity measurements, using a sun photometer, were taken in the northwest area of Columbia Falls, at the William Campbell home.

Missoula

The study area is the "Missoula Valley", which consists of a portion

of the Bitterroot Valley to the south, and the Clark Fork Valley extending from Missoula to twenty miles to the west-northwest. The valley is shielded by the Continental Divide sixty to eighty miles to the east and the Bitterroot Range twenty miles to the southwest, resulting in a semiarid climate. The area experiences frequent climatic temperature inversions in the fall and winter seasons.

The Lion's Park site is located in urban southeast Missoula. The equipment trailer is located in the northeast corner of the park. The park occupies approximately one square city block and is bordered to the north and west by commercial areas and to the south and east by residential areas.

The site was equipped to monitor continuously surface wind speed, wind direction, temperature, dewpoint temperature, solar radiation, pressure and visual range. The site also provided data on upper level wind speed and direction.

Surface meteorological data was also obtained from the Missoula National Weather Service (NWS) station, located at Johnson Bell Airport, approximately six miles west of downtown Missoula. The data consisted of wind speed, wind direction, temperature, dewpoint temperature, pressure, solar radiation, precipitation and cloud cover. The Missoula NWS station also provided breakdown of hourly visibility into quadrants during daylight hours.

Surface wind speed and wind direction were measured continuously at a site on the Clifford Olofson property. The site is located on Bitterroot Road (Highway 93) approximately two miles southwest of the Missoula city limits, near the mouth of the Bitterroot Valley.

Surface wind speed and wind direction were measured continuously at the Bruce Stiegler site. The site is located in the Grass Valley Farm area, approximately seven miles west-northwest of Missoula.

The University of Montana site is located on the property of the University. The equipment is in the northeastern most corner of the Physical Plant Complex. The site is bordered by the Clark Fork River to the north and experiences extreme wind conditions from the mouth of the Hellgate Canyon to the East. The site is equipped to monitor continuously surface wind speed and wind direction.

The Hoerner-Waldorf company provided surface wind speed and wind direction data to the Air Quality Bureau in Helena. The data was obtained from the Hoerner-Waldorf site #1, located three-quarters of a mile southwest of the main Hoerner-Waldorf complex.

KECI Television provided temperature data from its transmitter station located on TV Mountain, approximately 7000 feet above the valley floor, ten miles northwest of Missoula. The data was used for lapse rate calculations.

Turbidity measurements, using a sun photometer, were taken at the St. Patrick School of Nursing. The area is mostly commercial, and located approximately one-half mile west of downtown Missoula.

Upper level wind and temperature measurements were made at the Northern Forest Fire Laboratory, approximately seven miles northwest of the city. A monitoring trailer (on loan from the U. S. Forest Service) situated in an open field one-half mile west of the main building. Measurements were made of upper level wind and temperature and atmospheric stability (acoustic radar).

III. DISCUSSION OF RESULTS

The following provides an area by area discussion of the monitoring results from the first year of MAPS meteorological studies.

Anaconda

Surface Meteorology

Surface wind data was assessed individually from five key sites (see Table 2). An intersite comparison and discussion of dispersion characteristics are also presented.

The Highway Junction site is situated at the mouth of the Anaconda Valley greater Deer Lodge Valley confluence, two miles northeast of the Anaconda Company smelter. Information available for discussion dates from December 1977 to April 1979. A frequency distribution of winds indicates the most prevalent winds were from the south-southwest to north-northwest (58 percent annually). The southerly influence was most noticeable from September through February. The northerly component was greatest during the spring season. A secondary maximum (19 percent annually) from the north-northeast to east-northeast was most pronounced from May to July. Least common winds were from the northwest to north and east to southeast (total of 16 percent annually). The highest average wind speeds were from south-southwest to west-northwest with equal distribution throughout the year. The lowest were from north-northwest to north and east-northeast to east-southeast, again with equal annual distribution. The highest monthly average was 6.2 meters per second (m/sec) from

west-north in December and the lowest was 0.2 m/sec from north in March. Notably, the site experienced a very small percentage (0.1 percent annually) of calm conditions due in some part to the westerly drainage winds from the Anaconda valley. These winds also contributed to the diurnal wind pattern of westerly component flow from late evening to mid-morning which was then altered by stronger prevailing winds. Since the drainage flow and the predominant flow are both westerly, the individual contribution of these winds to the total flow is difficult to determine. However, their intensity during early morning was at times sufficient to overcome prevailing easterly flow (as observed by plume configuration). As expected, this pattern is most noticeable during the warmer months. Diurnal maximum wind speeds occurred around 1400 Mountain Standard Time (MST) somewhat earlier during the winter season.

At the Lincoln School site, located in the City of Anaconda, data collection was begun in July, 1978. Complementary data from the Water Office site (located one-half mile from the Lincoln School site) was used to complete a full year of data. The information was treated as provided by one source. In all months the predominant winds were from the west-northwest (52 percent annually). No definite secondary maximum was noted. However, winds from the east-southeast to southeast did occur in all months (12 percent annually) most pronounced in July, December, and January. Least common winds were from the north-northwest to east-northeast (9 percent annually). The average wind speed was greatest during the spring season and least during the winter season. The strongest average winds were from west-northwest to northwest, the maximum being 5.1 m/sec from west-northwest in April. The lightest average wind speeds were from north-northwest to south-southeast, the minimum being 0.2 m/sec from the north in April. Calm conditions were also infrequent at this site, 0.4 percent annually. Diurnal wind patterns were similar to those experienced at the Highway Junction site. However, with two exceptions due to the site loca-

tion, it was not as susceptible to changes influenced by wind flow within the Deer Lodge valley and the pattern was affected by southeast wind, rather than the northeast winds experienced at the Highway Junction site. This may have been caused by geographical alteration of wind flow.

A description of C-Hill and Weather Hill sites is presented in Table 2. These sites are located at elevations relative to the smelter stack height and are useful in assessing plume trajectory.

C-Hill information was available from January 1978, to May 1978, inclusive and September 1978 and January 1979. The most common winds for all months were from the south-southwest to west, averaging 61 percent. However, winds from the west alone averaged 21 percent for all months concerned. Winds from the east to south occurred an average of 25 percent, ranging from 19 percent in May to 32 percent in April. Least common winds for all months were from north-northwest to northeast. Average maximum monthly wind speeds were from the west for all months ranging from 4.7 m/sec in January, 1979 to 9.8 m/sec in April 1978. The lowest average wind speeds occurred in the directions of least common wind.

Weather Hill information was available from January 1978 to January 1979, except for the months of summer 1978. The most common winds were from the west-southwest to west-northwest for all months, averaging 48 percent and ranging from 31 percent in November to 59 percent in September. At this site winds from the west alone averaged 26 percent ranging from 20 percent in November to 40 percent in October. Distribution of predominant winds did not indicate a seasonal pattern for the months concerned. Winds from the east to south averaged 23 percent ranging from 15 percent in May to 34 percent in

September. Least common winds were generally from the north-northwest to northeast. Average maximum monthly wind speeds were from the south to southwest and west-northwest. The lowest average monthly wind speeds occurred in the directions of the least common wind.

Although these sites are useful as predictors of plume trajectories, their location represents a major shortcoming with respect to pollutant dispersion. Surface or near surface winds may often be quite different than those indicated at these elevated sites. In other words, where the stack plume trajectory is dictated by westerly winds, easterly winds at the surface may disperse the roof emissions or downwashed stack emissions toward the city of Anaconda. Information regarding this would be useful and could be accomplished with the installation of another wind system, preferably at or near the smelter converter roof.

The directional wind component common to all sites is westerly, accounting for over 60 percent of the total annual directional distribution for the Lincoln School and Highway Junction sites. In terms of a relationship between pollution and population, this is a positive feature (of natural conditions) for the city of Anaconda, located to the west-northwest of the smelter operations. The westerly drainage winds of the Anaconda Valley are also beneficial to this population area regarding positive dispersion (pollution moving away from the city). However, this particular population center does experience the potentially less desirable easterly winds during all months of the year, over 25 percent of the annual directional distribution. Populated areas to the north-northeast and east-northeast to southeast are more distant from the pollution source but are situated in the primary and secondary wind distribution maxim.

Upper Air Meteorology

Pilot balloons were released from the Highway Junction Site for a period of one year beginning in May 1978. From these flights, wind speed and wind direction as a function of height was computed. Wind distribution frequencies and average wind speeds were tabled for various levels up to 1500 meters above ground level (AGL). Information from the morning and afternoon releases is discussed individually followed by a comparison study.

Review of the morning directional wind distribution indicates a shifting of the predominant winds with respect to height. At the surface the most common direction is from the southwest to west (50 percent annually) for all months except November and December, when south to southwest winds were most common. There was no significant secondary maximum at the surface as well as at any height AGL. However, winds from south to west-northwest comprised 73-75 percent of the annual average directional flow. The least common wind directions were from east-northeast to southeast and northwest to north-northwest. At 300 meters AGL the southerly component was greater, the predominant winds were from the south to southwest (43 percent annually) for all months except May, when they flowed from the west-northwest or northwest sector. Winds from the south-southeast to west-northwest accounted for 77 percent of the annual distribution. The least common directions were northeast to southeast. At 750 m AGL a definite reversal occurs. The predominant winds are then from west-southwest to west-northwest (57 percent annually) for all months and winds from the south to west-northwest comprise 83 percent of the annual distribution. The least common directional flow is northeast to southeast. At 1500 m AGL the predominant winds are from north to northwest for all months except February and May, when the most common winds were from the

southwest to west. Winds from the southwest to northwest accounted for 75 percent of the average annual distribution. Least common winds were from north-northeast to south. Wind speeds at all levels were directly proportional to the highest and lowest frequency distributions as well as increasing heights.

The afternoon distribution of upper air winds are more complex than those in the morning. At the surface a bimodal distribution of predominant winds exists. During the summer and spring seasons, the most common directions are from north to east (38 percent annually), and during the winter and autumn months, the most common are south-southwest to west-northwest (41 percent annually). The secondary maxima are the predominant winds with respect to each other seasonally. For all months the least common directions are east-southeast to south and north-west to north-northwest. At 300 meters AGL the most common winds are from south-southwest to west-northwest (52 percent annually) except during the months of summer and the month of January, where the predominant flow is from north to northeast. This directional arc is also the secondary maximum comprising 30 percent of the average annual distribution. Least common winds were from east-northeast to south for all months. At 750 meters AGL the most common wind directions were from southwest to west-northwest for all months making up 86 percent of the average annual distribution and directional flow from south-southwest to northwest accounted for 72 percent. Least common wind directions were north-northwest to south. AT 1500 meters AGL the most common wind directions were southwest to northwest accounting for 80 percent of the annual distribution. However, from November to May the most common winds shift to the west-southwest to northwest. The least common winds were from north-northwest to south-southwest. The generalization made

regarding wind speeds during the morning measurements also holds true for those made in the afternoon.

A review of morning and afternoon upper air winds indicates the diurnal differences and the heights to which they are extended. These differences are most pronounced at the surface due primarily to the drainage winds the site experiences at the time of morning measurements. The dissipation of this effect is noted in November and December when temperatures were low and snow cover persistent. The magnitude of difference decreases with height as winds become less influenced by drainage winds and topography.

Mixing heights were computed from pilot balloon temperature soundings originated at the Highway Junction site dating August 1978 to April 1979.

In the mornings, mixing heights of near zero to 100 meters were most common for all months except December and April, averaging 38 percent and ranging from 67 percent in October to 22 percent in December. The majority of mixing heights were from near zero to 250 meters for all months except September. For all months at least 64 percent of all mixing heights were from near zero to 750 meters. Mixing heights greater than 1500 meters occurred only in October and March, an average of 6 percent. Average wind speeds through the mixed layer were greatest in October and December and the lowest in January (which had 100 percent of the mixing heights less than 500 meters). For both the autumn and winter seasons the majority of morning mixing heights were from near zero to 250 meters. However, mixing heights greater than 500 meters were more common to the autumn season. Likewise, average wind speeds through the mixed layer were greater during the autumn season.

The most common afternoon mixing heights were greater than 250 meters, occurring at least 65 percent of the time for all months. Mixing heights greater than 1000 meters occurred 39 percent of the time, ranging from 0 percent in January to 79 percent in October. Mixing heights from 250-500 meters occurred

TABLE 3
Holzworth Lapse Rate Categories (Modified)
Values in deg C/100m

<u>Non-Inversion Class</u>	<u>Lapse Rate</u>	<u>Description</u>
1	≤ -1.60	Very Superadiabatic
2	-1.21 to -1.60	Superadiabatic
3	-0.81 to -1.20	Near Dry Adiabatic
4	-0.41 to -0.80	Near Standard Atmosphere
5	0.00 to -0.40	Weak Lapse
<u>Inversion Class</u>	<u>Lapse Rate</u>	<u>Description</u>
1	0.00 to +0.47	Weak Inversion
2	+0.48 to +1.14	Moderate Inversion
3	+1.15 to +2.82	Strong Inversion
4	+2.83 to +6.00	Very Strong Inversion
5	$> +6.00$	Extreme Inversion

(Holzworth, 1974)

an average of 52 percent in the months of November, December and January. A seasonal variation is evident in that mixing heights greater than 1000 meters are more common in all but the winter months. Therefore, average wind speeds through the mixed layer are greater in those months with the greater mixing heights, from 7.5 m/sec in April and September to 3.5 m/sec in January. Furthermore, they are stronger than their morning counterparts. The autumn season has no mixing heights less than 250 meters with 52 percent greater than 1000 meters. Conversely, the winter season had mixing heights from near zero to 250 meters 18 percent of the time, but only 16 percent greater than 100 meters.

Inversion information was also computed from the temperature soundings dating August 1978 to April 1979. Inversions were categorized according to their base height and thickness. Also, they were each assigned a Holzworth strength classification 1 through 5, 1 being the weakest and 5 being the strongest and most intensive (see Table 3).

Morning inversions were mostly surface based with a thickness ranging from 1-250 meters. These were mainly Holzworth type 3. Elevated inversions had base heights ranging from 100-1500 meters with little definite seasonal pattern. These were generally thinner (1-100 meters) and less intense (Holzworth type 1) than the surface based inversions. No inversions occurred at an average of only 3 percent per month. For all months, distribution of inversion parameters were similar.

There were very few afternoon surface based inversions, occurring only in November, December, January and March. Most base heights were greater than 250 meters and varied considerably. The most common thickness were from 1-250 meters. These were mainly Holzworth types 1 and 2. The stronger after-

noon inversions were generally based from 250-750 meters aloft. There were no definite monthly distribution patterns except for the no inversion occurrence figures. The months of October through January experienced no inversions an average of only 2 percent per month as compared to an average of 24 percent for the other months.

In the morning, surface based inversion frequencies averaged 75 percent for all months, as compared to 12 percent in the afternoon. Average lapse rates in the first inversion were greatest (more intense inversion) in the mornings (1.7 degrees C/100 meters vs. 0.8 degrees C/100 meters). A winter seasonal variation is apparent in that the occurrence of afternoon surface-based first inversions and their intensity increase, whereas in the mornings a decrease in occurrences is noted.

As previously mentioned, mixing height and inversion information was computed from temperature sounding data. Monthly and seasonal averages of these soundings have been plotted for September 1978 through April 1979. These clearly indicate the large monthly variations in atmospheric temperature profiles. This is most noticeable during the winter season as the atmosphere cools less rapidly with respect to height. Dry adiabatic lines have been plotted on the morning profiles to indicate the average monthly mixing heights.

Stability was initially determined from interpretation of acoustic radar records. Further analysis as to frequency and degree of stability was made using cloud height and cover and wind speeds (Gelhaus, 1979b). The stabilities were determined for two-hour periods continuously throughout the months dated May, 1978 to March, 1979. The data indicates the expected distribution of the various categories for this area. During the summer the greatest percentage of hours are in the categories of neutral to moderately unstable. However,

with the approach of winter, the greatest percentage of hours is shifted to either neutral or to slightly stable categories. This shifting trend is generally consistent for all categories and all months. A reversal of this trend is expected with the return of warm months. It must be noted that cloud height and cover data used in stability determination were obtained from observations at the Butte office of the Federal Aviation Administration (FAA). Actual meteorological conditions in Anaconda are often much different than those experienced in Butte, particularly in the winter and spring seasons. Also, a large portion of stability data could not be calculated since FAA observations were often missing.

Frequency tables of first (lowest) and second (second lowest; if multiple inversions) inversions were also derived from acoustic radar records.

Most first inversions for all months were surface based. During May and June most inversions were 100-300 meters thick. For the months of July through September, inclusive, the inversions were equally 0-100 and 100-300 meters thick. However, the continuing trend indicated that by November inversions 300-500 meters thick were nearly as frequent as those 100-300 meters. A reversal of trend occurred in December, and by February most first inversions were again 100-300 meters thick. Daily inversion analysis was separated into six-hour blocks beginning at midnight (0000 MST). Continuation of inversions did not extend into the 0600-1200 MST block until September and continuation or formation of inversions did not extend into the 1200-1800 MST block until November. This individual trend was essentially reversed by March 1979.

Second inversions were infrequent and occurred primarily from November to March. These were mostly based from 200-400 meters and were 100-300 meters

thick. Generally, these are not as intensive as the first inversions, particularly those with base heights greater than 400 meters.

The average monthly inversion formation times and lifting times are a function of the time of the year and the associated radiational effect. During the year the formation time varies from 2000 MST in June to 1700 MST in January. Lifting times for the same months are 0630 MST and 1030 MST, respectively. The inversion angle of ascent (rate of rise from the surface relative to a two-hour time period) in June averaged 175 meters as compared to 90 meters in January. This measurement can be complicated by a variety of meteorological events or conditions. Snow cover in the winter often prevented an inversion from breaking up, resulting in its continuation for more than one day. Also events such as heavy precipitation, high winds or frontal passage often resulted in abruptly breaking up an inversion.

Temperature lapse rate data from the Anaconda Company's C-Hill meteorological tower was compared with lapse rates obtained from the temperature soundings to determine whether the C-Hill data could be usable for future stability evaluations. Both lapse rates were determined for the same time, both using the same surface temperature. The C-Hill sensor is at an elevation of 7179 feet, 840 feet higher than the smelter stack. Data collected from August, 1978 to March, 1979 indicates relatively good comparisons for both the morning and afternoon measurements, with the exceptions of October and November, 1978. There are several factors which can account for discrepancies in the comparisons such as incorrect assumptions of pibal ascent rates during the vertically active spring and summer seasons. Other factors are terrain influence on temperature and pibal ascent rates and distance separation between the soundings and the tower sensor. These singular lapse rates can be misleading

in that a variety of individual lapse rates may exist within them. A complete year of data will be necessary to establish fully whether these measurements can be used as a predictive tool for inversion conditions.

Billings

Surface Meteorology

Surface wind data from two sites in the Billings area were available for this report (see Table 2). These are the Billings Airport (National Weather Service), located on the rimrocks north of the city, and Billings Central Park in downtown Billings. The data from the Central Park site consists of hourly means of wind speed and direction, while the National Weather Service data is composed of instantaneous values of wind speed and direction at three-hour intervals (three and six hourly synoptic observations). Accordingly, caution should be exercised when comparing the National Weather Service data with those from the other site.

Surface wind data was gathered at Central Park beginning in August 1978. Data through December 1978 were examined for this report. The prevailing wind at this site for all months was from the west, with frequencies from this direction ranging from 21 percent in August to 54 percent in December. Secondary maximums of wind frequency were noted from the north and northeast through east in August, from the north and east in September and October, and from the north-northeast through northeast in November. The least common wind direction during all months was from the south-southeast. Average wind speeds ranged from about 0.5 to 4 meters per second (m/sec) and averaged about 2 m/sec. Wind speeds were lowest in August and highest in December. Highest average wind speeds were generally from the northwest and the lowest were usually from

the northeast. Calm conditions occurred 13 percent of the time in August and 9 percent of the time in September, but decreased thereafter. No calm conditions at all were noted in November and December.

Wind observations taken by the National Weather Service at the Billings airport were available for the months April 1978 through February 1979. Prevailing winds at this site were from the southwest or west-southwest except April, May and July 1978. During April and May, the prevailing wind was from the northwest, while in July it was from the north. Secondary maximums of frequency from the north and northeast were noted in April, August, October and November. A secondary maximum from the southwest occurred in July. The least common wind directions for all months were southeast and south-southeast.

Average wind speeds ranged from about one to nine meters per second and averaged about four meters per second. Average speeds were slightly lower in summer than in other months. The percentage of calm conditions ranged from 0.8 percent to 22 percent and varied insignificantly from month to month.

Billings' location about fifty miles northeast of the Rocky Mountains is the most important factor influencing the wind patterns of the area. Foehn-type, or "chinook" winds blowing down from the mountains insure that the prevailing wind direction is southwest throughout the year. Of major importance also is the Yellowstone River Valley which in this area is orientated southwest through northeast and averages ten miles wide and about 300 feet deep.

The two wind sites in Billings show similar wind frequency patterns, the prevailing wind being westerly at Central Park and from the southwest at the Airport. The more westerly winds at Central Park may be a channeling effect due to its location in the valley, which in this area runs nearly east-west and is quite narrow. Wind velocities are lower in Central Park than at the airport,

probably a consequence of the park's location in the center of the urban area.

Upper Air Meteorology

Pilot balloon and temperature sonde soundings were conducted at the Billings Vo-Tech site, located on the west side of Billings beginning in July, 1978. Because of numerous problems with the equipment and operator, not as much data was gained as had been hoped. However, additional data will be collected in the next year of the study.

Surface winds at pibal launches were generally from the southwest during all months, both morning and afternoon. The only exception to this pattern occurred during the mornings in August 1978, when surface winds were mainly from the north. Average wind speeds were light, ranging from 0.4 m/sec on September mornings to 5.5 m/sec on November afternoons. Calm conditions were frequent in the mornings during August and September, but became progressively less frequent during the fall and winter. Calm conditions were noted only twice during afternoon runs, once in August and once in November. In general, wind speeds were least in July and August 1978 and greatest in January 1979. Winds were almost always greater in the afternoons than in the mornings, the only exception being in January 1979.

Winds aloft up to 750 meters were similar in direction to those at the surface, being mainly from the southwest or west-southwest. There were a few exceptions to this pattern, mostly in July and August when winds from 200 to 500 meters were mostly from the northeast. Even then, a secondary maximum of wind frequency from the southwest was noted. At levels above 750 meters, the wind began to veer with height, becoming westerly at 1000 meters and generally from the west-northwest at 1500 meters and above. Average wind

speeds increased with height, becoming about three times greater at 1500 meters than at the surface. During most months winds between 200 and 1000 meters were greater in the morning than in the afternoon. Average wind speeds were greatest in January and least in July and August.

Information on inversion base heights, thickness and Holzworth types was obtained from temperature sonde traces. Inversions were present during nearly all morning runs. Most of these were surface-based and from 100-250 meters thick. Very few surface-based inversions were more than 500 meters thick. Most runs had one or more elevated inversions present in addition to the surface based one. These elevated inversions were most often less than 100 meters thick, although a few ranged up to between 250 and 500 meters thick. These inversions were most often based between 100 and 1500 meters above ground level, with the range 250 to 500 meters being the most common. Elevated inversions were also weaker than surface-based ones, most being of Holzworth types 1 or 2, but with some types 3 and 4 being noted. By contrast, most surface-based inversions were of Holzworth types 2, 3 and 4, with type 2 being the most common.

During the afternoon runs, inversions were much less common than during the mornings. The frequency of surface-based inversions showed a pronounced seasonal variation, being almost absent during the months August through November 1978, but becoming present in about one-third of the runs in December 1978 and in about one-fifth of the runs in February and March 1979. There were no surface-based inversions noted during the January afternoon runs. The frequency of elevated inversions also showed a seasonal variation, with only about half the runs in the months of August through November 1978 having any elevated inversions present, while in December 1978 and January 1979 all

afternoon runs had elevated inversions present. In February 75 percent of runs had elevated inversions present and by March 1979 the frequency of occurrence had returned to 50 percent.

Mixing heights, average wind speed through the mixed layer and the average lapse rate below the first inversion were calculated for each temperature-sonde run and monthly averages of these parameters were computed. This information indicates that the most common morning mixing heights were less than 250 meters for all months except December and February.

In December morning mixing heights of 250-500 meters were most common and in February 500-750 meters. By season, average morning mixing heights were 100-250 meters in autumn and 250-500 meters in winter. The average wind speed through the mixed layer was higher during the winter than in the summer and fall and ranged from 2.8 m/sec in August to 12.1 m/sec in January.

During the afternoons, the average mixing height was generally greater than in the mornings. October, November and March had average mixing heights greater than 500 meters, with October showing an average value greater than 1500 meters. August and February showed the lowest values, with average mixing heights between 100 and 250 meters. The average wind speed through the mixed layer ranged from 4.1 m/sec in August to 14.6 m/sec in November. These values were greater than those noted in the mornings with the exception of January.

In general, four seasonal trends are apparent: (1) morning mixing heights tend to be lower in summer and autumn than in winter; and (2) afternoon mixing heights tend to be lower in winter than in summer and autumn. The average wind speed through the mixed layer tends in the mornings to be lowest in summer and highest in winter, while the average wind speed through the mixed layer in the afternoons tends to be greatest in the autumn and least in the summer.

An acoustic radar was operated at the Billings Vo-Tech site beginning in late August 1978. Data from September 1978 through March 1979 were examined for this report. Because of its location in the bottom of the Yellowstone Valley, the Vo-Tech site can be considered representative of most of the city of Billings, as well as much of the surrounding area in the valley.

A review of the first inversion (lowest inversion) frequency of occurrence tables shows that surface-based inversions between 100 and 300 meters thick were the most common during all months. Inversions were present most of the time during the nighttime hours (0000 to 0600 MST), but were seldom present during the afternoon. The frequency of occurrence of nighttime inversions was similar from month to month, but afternoon inversions were more common in the winter months, but even then occurred less than 20 percent of the time. The time period 0600-1200 MST shows the greatest seasonal variation in inversion frequency, with inversions being more than twice as common during the winter months than during the autumn. This is probably a consequence of the shorter days during the winter.

Elevated inversions were quite uncommon, accounting for only 5 to 20 percent of all inversions noted. There did not appear to be any significant monthly or seasonal variation in the frequency of those inversions. Elevated inversions were nearly always less than 100 meters thick and generally were based from 100 to 300 meters above ground level.

Second inversions (second lowest inversion if multiple inversions were present) were very uncommon in Billings during this study, occurring less than 5 percent of the time. With only one exception, all were less than 100 meters thick, and all were based from 200 to 400 meters above ground level. Second inversions were more frequent in the autumn than during the winter. The time

of occurrence varied by season also, with autumn inversions all occurring during the night and morning hours, while winter inversions occurred equally during all time periods except 0000-0600 MST, when there were none recorded.

A two-hour stability analysis was performed based on acoustic radar data, together with cloud cover and wind speed data from the NWS station at Billings (Gelhaus, 1979b). Because of the two to three month delay in receiving the NWS data from the National Climatic Center in Asheville, North Carolina, only data through February 1979 was available for this report. For this analysis, stability categories ranging from "A", very unstable, to "F", moderately stable, were computed for two hour time intervals throughout the months. During all months with data available, categories D and E were most common, occurring from 36 to 86 percent of the time. The most uncommon categories were A (0%) and B (0.3 percent in September and October, 0 percent thereafter). Category C, slightly unstable, showed the greatest monthly variation, occurring 16-19 percent of the time in September and October, but only 4.4 and 0.3 percent in November and December respectively and 0.6 percent in January and 0 percent in February. Broadly speaking, September was the least stable month and December was the most stable.

The diurnal variation in stability of course was similar from month to month with the most stable conditions occurring at night and the most unstable conditions occurring during the afternoon. The transitions between nighttime and daytime conditions generally occurred within two hours after sunrise and sunset. The only significant variation from month to month was in the daytime stabilities. Afternoon stabilities in September and

October were generally C's, while in November category D was most common. In December, categories D and E were almost equally common and in January and February category D was most prevalent. Consequently dispersion will be most inhibited in November through February at this site.

A record was kept of the times the morning inversion lifted and the evening inversion formed, as recorded by the acoustic radar. An analysis of the rate of ascent of the morning inversion as it lifted off the ground was also made. This type of information is valuable, since the duration of a surface-based inversion will have an important bearing on the concentration of pollutants near the surface, and because the rate of ascent of the inversion will affect the length of fumigation episodes.

Data from Billings were available for the months of September 1978 through February 1979, inclusive. During December, January and February surface-based inversions were seldom seen due to the windy conditions which generally prevailed. During the fall months, inversions usually formed about one to two hours after sunset and lifted about one and one-half hours after sunrise. The inversion rate of ascent varied from 145 meters/2 hours in September to 200 meters/2 hours in October. Not enough data were available to indicate any seasonal trends.

Butte

Surface Meteorology

Surface wind data was assessed individually from three key sites (see Table 2). An intersite comparison and discussion of dispersion characteristics is also presented.

Surface wind information was received from the Federal Aviation Administration (FAA) located at the Silver Bow County Airport. The facility

itself is generally located in the southern end of the Centennial Valley. Information available for discussion dates from January 1978 to March 1979. The frequency distribution of winds at this site indicates the most prevalent winds were from the NW quadrant particularly during the spring season. For all months a secondary maximum from the south-southeast to south was noted. This was greatest during the winter season. For all months least common wind directions were bimodal in frequency distribution; from the north-northeast to east-southeast and south-southwest to southwest. The greatest average monthly wind speeds varied randomly with respect to direction. The strongest average winds 4-6 m/sec were from the west quadrant. The lowest speeds 0-2 m/sec were from the northeast to east-northeast. The site experiences calm conditions ranging from 11 percent in April to 36 percent in January 1979. Drainage winds experienced at this site are somewhat difficult to assess due to the sites location and lack of valley perimeter instrumentation. However, it can be assumed that they were from the south-southeast to south, direction of secondary maximum distribution, since they were consistent in all months but especially noticeable during the summer and autumn seasons. Diurnal maximum wind speeds occurred between 1400-1600 MST, somewhat earlier during the winter season.

Surface wind data collected from the Alpine West and Hebgen Park sites date January 1978 to May 1978 and June 1978 to December 1978, respectively. Review of site locations and respective data indicates that information cannot be used to complement each other for a full year of data.

The Alpine West site is located on the west side of Butte. The most common winds were from the east-southeast to south-southeast in

January and February and from the west-northwest to north-northwest in April and May. Of the other directional sectors there appears to be no definite directions of least common winds. Average wind speeds are greatest from the west-northwest to north-northwest for all months totaled and least from the north to southeast in January and February and from southeast to southwest in April and May. Calm conditions are very infrequent; however, the highest average wind speed is not extreme, 4.2 m/sec from the north-northeast in May. There appears to be little indication of a definite drainage wind system for these months. Any diurnal patterns are inconsistent.

The Hebgen Park site is centrally located in the city of Butte, south of the Berkeley Pit. The most common winds for all months were from the west-southwest to west-northwest, the southerly component greater during the cooler months (September through December). Wind frequency distribution from all other sectors is quite random indicating no definite secondary maximum or least common directions. Average monthly wind speeds were low for all months concerned ranging from 0.4 to 4.2 m/sec. These were greatest from the west-northwest to north-northwest for the average of all months. Calm conditions at this site were also very infrequent occurring only in November and December. The strongest diurnal wind speeds occurred at 1700 MST in June and eventually moving earlier to 1500 MST in December. Again, inconsistency in diurnal patterns and monthly directional wind distribution do not support an indication of a definite drainage system. More information is necessary to make a more accurate determination.

Review of wind roses from the sites in the northern end of the valley

indicate wide, almost random monthly wind distributions. This information compiled with the fact that winds are generally light and the area experiences inversion conditions throughout much of the year (this is to be discussed later) provides for few predictable dispersion characteristics. Surface winds recorded at the FAA facility are more informative with regard to dispersion characteristics. The predominant winds from the west-north to north-northwest are active for all months, particularly during the spring and summer seasons. However, winds from the south-southeast to south, particularly in the autumn and winter season (seasons of greater atmospheric stability) are also common.

Pilot balloons were released at the Butte Airport site, and wind speed and direction as a function of height were compiled from these flights. Data analysis is for June 1978 to April 1979. Directional distributions and average speeds were tabled for various levels up to 1500 meters above ground level (AGL). Information obtained from the morning and afternoon releases will be discussed individually and then a comparison of information will be presented.

Review of the morning directional wind distribution indicates a slight shifting of the predominate winds with respect to height (AGL). At the surface the most common direction is from the south-southeast to west with greater than 35 percent average annual frequency for all months, the maximum occurring in December (86 percent), and the minimum in June (27 percent). A secondary maximum from the north-northeast is noted in September and January through April, inclusive. The least common directions are from the northeast to east and west-northwest to northwest. AT 300 meters AGL the westerly component was more marked as the most common winds were from the south to west. The exceptions to this is the months of August, October, December and January, whose most common winds were from the northwest to north-northeast. The least

common directions were from the east-southeast during the months of August through January inclusive, and from the west to northwest for the months of January through April inclusive. At 750 meters AGL the most common winds were from the south-southwest to west for all months except June and July, which had a greater frequency of winds from the east to south. The least common wind directions were from the north to south-southeast with the exceptions of June and July. At 1500 meters AGL the predominant winds were from the southwest to west-northwest and the least common were from the north to south. Wind speeds at all levels were generally directly proportional to the frequency distribution as well as with increasing heights (AGL). Average maximum monthly speeds ranged from 4.5 m/sec at the surface to 20.5 m/sec at 1500 meters AGL.

Mixing heights were computed from pilot balloon - temperature sounding that originated from the Butte airport site dating September 1978 to April 1979.

In the mornings, mixing heights from near zero to 100 meters were most common for all months ranging from 27 percent in April to 90 percent in October and averaging 59 percent for all months. All months experience mixing heights of at least 500 meters, averaging 84 percent. All months except September and January had mixing heights over 1000 meters (an average of only 11 percent, however, for those months). Seasonally, mixing heights were slightly greater during the winter as compared to autumn, which had 75 percent of the time near zero to 100 meters. Average wind speeds were likewise greater in the winter season.

The most common afternoon mixing heights were those greater than 1000 meters except November through February inclusive, when mixing heights from near zero to 250 meters were most common. Mixing heights greater than 1000 meters averaged 47 percent and ranged from 9 percent in January to 75 percent in September. A seasonal variation is apparent. Mixing heights greater than

1000 meters are much less common during the winter, averaging 21 percent as compared to 56 percent for all other months. Conversely, mixing heights from near zero to 250 meters averaged 20 percent in autumn as compared to 55 percent in winter. Average wind speeds were greatest during those months with the greater mixing heights. For all months these speeds averaged 5.5 m/sec ranging from 1.8 m/sec in January to 7.2 m/sec in September. The afternoon wind speeds were greater than those in the morning for all months.

Inversion information was also computed from the temperature soundings dating September 1978 to April 1979. Inversions were categorized according to their base height and thickness. Also, they were each assigned a Holzworth strength classification 1 through 5, 1 being the weakest or least intense (Table 3).

Morning inversions were mostly surface based averaging 36 percent for all months and ranging from 28 percent in October to 72 percent in January. These were mostly 1-500 meters thick. Also, these were mainly Holzworth type 1 and 3 for September to December and types 1 and 2 for January through April. Seasonal distribution (autumn vs. winter) was similar with the exception of the Holzworth types (autumn inversions were somewhat more intense). Elevated inversions ranged widely with respect to base heights, mostly from 250 to 2000 meters. They were generally 1-250 meters thick and Holzworth types 1 and 2. Only the month of February experienced any percentage (5 percent) of no inversions in the mornings.

There were very few afternoon surface based inversions. These occurred in the months of November through March inclusive averaging only 7 percent, the greatest number of them occurring in January (11 percent). Base heights varied considerably, the lowest heights occurred in the months already mentioned.

These inversions were mostly 1-250 meters thick and Holzworth types 1 and 2. The most intense inversions (type 4 or 5) were based from 1-250 meters and occurred mostly in the winter months. Seasonal distribution of the afternoon inversion parameters were similar; however, the more intense inversions occurred during the winter (as compared to autumn). All months except January experienced conditions of no inversions averaging 16 percent ranging from 0 percent in January to 36 percent in February. It should be noted that January was an unseasonably cold month, as was the entire winter season.

In the mornings, surface based first inversions (inversions nearest the ground) averaged 83 percent, ranging from 100 percent in October and February to 46 percent in April. Afternoon values averaged 13 percent and ranged from 36 percent in January to 0 percent in September, October and April. First inversion intensities were greater in the mornings as compared to those in the afternoons (2.1 degrees C/100 meters versus 0.9 degrees C/100 meters). Seasonally, the inversion strengths (both morning and afternoon) were greater in winter than in autumn.

As mentioned, mixing height and inversion information was computed from temperature sounding data. Monthly and seasonal averages of these data were plotted for September 1978 through April 1979. These plots clearly demonstrated the intense diurnal inversions experienced from late autumn through winter.

Stability information was initially determined from interpretation of acoustic radar records. Further analysis as to frequency and degree of stability was made using cloud height and cover and surface wind speed data provided by Butte FAA. The stabilities were determined for two-hour periods continuously throughout the months dating from February 1978 to December 1978. During the summer the greatest percentage of hours are in the categories of neutral to slightly unstable, average 47 percent. However, with the approach of winter, the greatest percentage of hours shifts to the neutral to slightly stable

categories. A reversal of this trend occurs during the spring. This shifting of trend is consistent for all stability categories. Information regarding inversion strength and duration and light wind speeds suggest that the percentage and categorization of stable hours has been underestimated. This may be due in part to the large percentage of missing FAA data.

Frequency tables of first (lowest) and second (second lowest of multiple inversions) inversions were also derived from acoustic radar records. First inversions were generally surface based for all months. Inversion thickness' of 100-300 meters and 300-500 meters were most common and equally proportioned with the exception of summer when thicknesses of 100-300 meters were predominant. Daily inversion analysis was separated into six-hour blocks beginning at 0000 MST. Inversion continuation into the 0600-1200 MST block existed for all months, and continuation or formation of inversions in the 1200-1800 MST block began as early as October. This is indicative of the short summer season and the overall moderate to cold highland climate of the area.

Second inversions were extremely infrequent in December and February through May (January data not available). These were generally based at 400 meters and were 100-300 meters thick and not as intense as the first inversions.

The average monthly inversion formation and lifting times are a function of the time of the year. During the year the formation time varies from 2100 MST in July to 1730 MST in February. Lifting times for the same months are 0730 MST and 1200 MST, respectively. The inversion rate of ascent (rate of rise from the surface relative to a two-hour time period) in July averaged 230 meters (when not ended abruptly) as compared to February, when no lifting was recorded. In this month the inversion either lasted all day(s) or ended abruptly. Abrupt endings were most often due to high winds or shower activity.

Missoula

Surface Meteorology

The air circulation in the Missoula Valley as it relates to air quality and pollution dispersion characteristics is complicated by the terrain, which create low-level wind patterns that vary significantly from one portion of the valley to another and from day to night. Of the six Missoula Valley sites (see Table 2) only Hoerner Waldorf #1 and the National Weather Service (NWS) Airport Station have records reduced for analyses that are of one year's duration or longer. Others have hourly data reduction from three to nine months' duration. However, all sites have been in continuous operation since the spring of 1978, and except for short-period outages due to equipment failure, these wind records will be reduced and processed in the next few months. The following discussion points out some features of the surface wind patterns in the valley.

At the Hoerner Waldorf #1 site, located approximately one mile southeast of the Hoerner Waldorf Plant, the diurnal wind pattern indicated monthly average minimum wind speed from 1 to 2 meters per second (m/sec), usually between 0200 and 0800 MST. The average maximum wind speed, from 2.5 to 5 m/sec usually occurred between 1600 and 1900 MST. During all seasons the prevailing wind direction was from one of the five sectors (out of 16) west through north, comprising 51 percent of the total hours. Southerly component winds occurred most frequently in winter and the sectors, southeast through southwest, comprised 31 percent of the total hours during the winter season. Of particular interest in this wind pattern is the late time-of-day occurrence of the maximum wind speed in spring and summer, usually about 1800 MST. The windiest month was April, while the least windy were October and January.

The NWS site is approximately 4 miles east-southeast of Hoerner Waldorf #1. Wind patterns similar to Hoerner Waldorf #1 are evidenced at this site, as would

be expected since both are in relatively open areas in the western part of Missoula Valley. Again, during all seasons the prevailing direction was from the west through north, comprising 40 percent of the total annual hours. However, the most frequently observed directions were west and west-northwest, while at the Hoerner-Waldorf site they were north and north-northwest. This more northerly prevailing wind at Hoerner Waldorf #1 site results from the influence of the almost north-south oriented mountain range a couple of miles to the west of the site. The diurnal wind pattern at the NWS site was very similar to Hoerner Waldorf #1, with a late afternoon or early evening maximum. On an annual average, wind speeds are slightly higher at the NWS site than at Hoerner Waldorf.

The University site is located near the mouth of Hellgate Canyon about 100 yards south of the Clark Fork River on the northeast end of the physical plant yard at the University of Montana property. The wind pattern during the eight-month period analyzed shows several interesting features. First, as would be expected, the pattern typifies canyon wind patterns so common in the mountainous west. The two easterly sectors east and east-southeast and the two westerly sectors, west and west-southwest, comprise about 80 percent of all wind directions recorded at this site. The easterly winds predominate at night and are generally stronger than the afternoon westerlies. The diurnal wind pattern changes at this site are very unlike the other Missoula Valley locations. Winds are lightest in late morning and evening hours during the transition periods from inflow to the valley (east wind) and outflow from the valley (west wind). Average wind speeds are higher than other valley sites, nearly 3.0 m/sec for the eight months analyzed.

The wind pattern at the Lion's Park site is characterized by more variability in direction and significantly lighter winds than the University site, the NWS site, and the Hoerner Waldorf sites. There is also a more southerly

component to the wind directions that prevail at Lion's Park. The five direction sectors from south through west include the prevailing monthly wind direction in all of the nine months analyzed, comprising about 40 percent of the total hours. Average wind speed for the nine month period in common with the NWS site shows 1.4 m/sec at Lion's Park and 2.4 m/sec at the NWS. Wind directions from the two sectors south and south-southwest comprise about 20 percent of the total hours at Lion's Park and only about 5 percent at the sites in the western part of the valley. Nighttime winds are generally light, averaging about 1.0 m/sec and the favored direction is southerly or easterly. The prevailing afternoon wind directions are southwesterly and westerly and the daily maximum wind occurs around 1600 MST, with average monthly speeds generally in the 1.5 m/sec to 3.5 m/sec range.

The period of record for the Olofson and Stiegler sites is too short to provide much comparison with other sites. In general, however, it appears that wind speeds are relatively light at Olofson's and directions favor a southerly and southwesterly component. At Stiegler's speeds appear somewhat lower than at Hoerner Waldorf #1 and the NWS site.

In summary, there is evidence that during the night and early morning hours the Missoula Valley represents an area of confluent winds. An easterly component, rather well indexed by the University (Hellgate) site, is often noted up to 1000 meters (see Upper Air Meteorology section of this report). During the day, with surface heating causing rising air currents, confluent winds would favor upward vertical motion, but it is most likely that at night they often serve to hold atmospheric air pollution in the Valley area, as the cool, dense air stays close to the ground surface.

Upper Air Meteorology

Pilot balloons were released from the USFS Northern Forest Fire Lab (Fire Lab) for a period of one year, starting May 1978. Pilot balloons were also released from the Lion's Park site beginning October 1978. From these flights, wind speed and direction as a function of height were computed. Wind distribution frequencies and average wind speeds were tabulated for various levels up to 2000 meters above ground level.

The lowest average morning monthly wind speeds were at the surface, 0.5 meters per second (m/sec) in July and October 1978 at the Fire Lab, and 0.6 m/sec at Lion's Park in January 1979. The highest average morning monthly wind speed occurred at both sites at the 1500 meter level in December 1978 with a speed of 14.9 m/sec at Lion's Park and 17.0 m/sec at the Fire Lab.

The lowest average afternoon monthly wind speed was 0.2 m/sec at the surface in January 1979 for both sites. The highest average monthly wind speed was 12.5 m/sec in September 1978 for the Fire Lab and 16.6 m/sec in November 1978 for Lion's Park, at the 2000 meter level for both sites.

Calm conditions were recorded as a morning surface wind speed at the Fire Lab site 38 percent for the summer season, 27 percent for the autumn season, and 13 percent for the winter season. Calm was recorded less often in the afternoon at both sites. The Fire Lab recorded 6 percent for the summer season, 24 percent for the autumn season, and 3 percent for the winter season.

The Fire Lab site was a definite pattern of wind from the surface to 2000 meters. The prevailing morning surface flow was northwest to north-northwest for the summer season, east for the autumn season, and west-northwest for the winter season. A prevailing east-southeast to southeast flow occurred for all three seasons at 200 to 750 meters.

A westerly component prevailed for both sites and all three seasons at the 1500 to 2000 meter level for the morning and afternoon. For all seasons at both sites more than 80 percent of the winds at 1500 meters were from the southwest through northwest.

Most likely because of its location in the valley (closer to mountains and canyons) the Lion's Park site exhibited more variability in wind direction in the lower 1000 meters above the floor of the valley than the Fire Lab site. The site also had a more southerly component at all levels, than the Fire Lab. The prevailing morning surface flow was west-southwest for the autumn season, and west for the winter season. A southeast to southwest flow occurred for all three seasons at 200 to 750 meters.

Wind speed and direction are greatly influenced by terrain. Missoula is almost surrounded by mountains and the terrain influence during the nighttime and early morning hours, when drainage winds predominate, often resulted in an easterly wind from the surface up to 1000 meters. Drainage winds subside shortly after sunrise. With daytime heating and the resulting vertical mixing, the afternoon atmosphere above the valley becomes more homogeneous. Then a prevailing westerly to northwesterly flow occurred at all levels from the surface to 2500 meters for both sites.

The prevailing direction when separated into sixteen sectors of the compass often comprises a rather small percentage of the total cases in the upper level wind study. When wind directions are summarized using a definition of "prevailing" as the four adjacent sectors (quadrant) that include the most cases, a more general analyses of wind direction and average speed results. The prevailing quadrant definition shows several secondary direction maxima whose direction frequency approaches the primary maxima. For example, the Fire Lab afternoon

balloon ascent during the winter season showed a primary direction of 38.6 percent for the east-southeast through south quadrant at 200 meters, with the secondary maximum of 35.4 percent for the northwest through north-northeast quadrant. Also for the afternoon winter season period, the 500 meter level shows a primary direction quadrant of 42.0 percent from east-southeast through south and 41.9 percent from west through north-northwest. For the same time period the Lion's Park site showed 38.3 percent of 500 meter level winds from southwest through west-northwest and 38.2 percent from east-northeast through southeast. Note that in the primary and secondary maxima quadrant breakdown, the directions are opposite and their frequency nearly equal.

Simply expressed, the mixing height above the earth's surface at any given time is that height to which air pollution is readily mixed with air. The MAPS method of estimating mixing heights is a relatively standard method utilizing the temperature profile of the atmosphere as measured by the balloon temperature soundings released shortly after sunrise and 1400 MST three days per week, weather permitting. These times of the day represent periods when the mixing heights are likely to be lowest (early morning) and approaching the day's highest (early afternoon).

By definition, the morning mixing height (as computed using a plot of temperature versus height taken from the morning sounding) is the height above the earth's surface represented by the intersection of the temperature profile trace and a straight line starting at the surface temperature plus 3 degrees Celsius (C), and having a slope of -0.98 degrees C/100 meters on the temperature versus height plot. This temperature lapse rate is known as the dry adiabatic and it represents very good vertical mixing conditions. The afternoon mixing height is computed in the same manner except the starting temperature of the

dry adiabatic lapse rate straight line is the temperature at the release time of the balloon plus two degrees Celsius.

Average monthly morning and afternoon mixing heights were computed by graphing averaged morning and afternoon temperature profiles. The average monthly morning and afternoon mixing heights (Table 4) are based on about ten soundings per month. Because of the limited sample, they may not typify true "average" mixing height conditions for each month. They do, however, show general agreement with diurnal and seasonal effects known to exist.

TABLE 4
AVERAGE MONTHLY MIXING HEIGHTS (meters)
USFS Fire Laboratory, Missoula, Montana

<u>Month/Year</u>	<u>Morning</u>	<u>Afternoon</u>
July, 1978	160	1600
Aug., 1978	170	1820
Sept., 1978	320	1350
Oct., 1978	140	1235
Nov., 1978	145	395
Dec., 1978	185	290
Jan., 1979	230	255
Feb., 1979	320	285
Mar., 1979	190	620

In the mornings, mixing heights of 100 to 250 meters were most common for the summer season; surface to 100 meters for the autumn season; and 250 to 500 meters for the winter season. For all months, 85 percent of all morning mixing heights were from the surface to 500 meters. Mixing heights greater than 1000 meters occurred in October, November and February, but very infrequently, an average of 3 percent. The months of July and December of 1978 and January and February of 1979 had no morning mixing heights greater than 750 meters.

The most common afternoon mixing heights were greater than 1500 meters for the summer season, and 250 to 500 meters for the autumn and winter seasons. For all months, 68 percent of afternoon mixing heights were from 100 to 750 meters, and 19 percent were greater than 1500 meters. The months of January and February 1979 had no afternoon mixing heights greater than 750 meters.

Forecasts of the height of the mixed layer and transport winds (direction and speed of winds in the mixed layer) are frequently used operationally in programs with a requirement for forecasting air pollution potential. At the Fire Lab site winds through the mixed layer were usually lighter in the morning than in the afternoon during summer and early fall, but about the same or slightly higher during late fall and winter. Wind speed through the mixed layer usually increases proportionately with the height of the mixed layer, since winds normally increase with height above the ground surface. Morning average wind speeds through the mixed layer were highest (4.4 m/sec) for February 1979 and lowest (1.7 m/sec) for January 1979. Afternoon average wind speeds through the mixed layer were highest (6.6 m/sec) for September 1978 and lowest (1.3 m/sec) for January 1979. Comparison of simultaneous temperature observations at the National Weather Service Airport Station (3210 feet Mean Sea Level, MSL) and the KECI TV Mountain site (6970 ft. MSL) provide an index to vertical mixing in the atmosphere over the Missoula Valley. In this 3760 foot layer of the atmosphere from the valley floor to the level of the TV Mountain Site, an average temperature lapse rate (taken from the Holzworth classification) of -0.81 to -1.21 degrees C/100 meters is generally indicative of good vertical mixing in the layer; from -0.41 to -0.81 degrees C/100 meters fair; from 0 to -0.40 degrees C/100 meters poor; and less than 0 degrees C/100 meters (inversion) very poor. Based on these four classifications, good mixing conditions occurred 55 percent of the time from April 1978 through February 1979 during the afternoons, with the range from

90 percent in May to 4 percent in February. At the other end of the scale, very poor mixing conditions were observed 32 percent of the time in the early morning, with the range from 63 percent in October to 10 percent in May.

Use of only two temperatures, at the bottom and top of the layer, to index vertical motion or stability at all elevations in the layer has definite limitations. Many nighttime temperature inversions resulting from radiational cooling occur with the top of the inversion less than 500 meters above the valley floor, well below the elevation of the TV Mountain site. While this type of nocturnal inversion restricts vertical mixing at night and early morning, the inversion is usually dissipated by mid-day (except in the winter season) allowing generally good vertical mixing in the afternoon. Although the strength or intensity of low-level nocturnal inversions cannot be identified using the average temperature lapse rate between the valley floor and TV Mountain, the lapse rates observed appear to reflect vertical mixing or ventilation conditions quite well, especially in the afternoons.

The major temperature inversions over the Missoula Valley that result in the most severe air pollution episodes during fall and winter are indexed quite well by the temperature difference between the valley floor and TV Mountain. These temperature inversions are large scale events, sometimes covering areas the size of several western states. They result from very large scale subsiding or sinking air motions in the atmosphere, frequently lasting for several days. The top of the inversion layer is 1500 meters or higher above the valley floor on many occasions, usually lowering on successive days until a weather change destroys the inversion.

Inversion information was computed from balloon temperature sonde data. Inversions were categorized according to base height, thickness and intensity

(Holzworth Inversion Classification--Table 3).

Without regard to thickness, the most common morning base height was 250 to 750 meters, with 34 percent for the summer season, 33 percent for the autumn season, and 32 percent for the winter season. Of the summer season, 18 percent were Holzworth type 2, of the autumn season 16 percent were Holzworth type 2, and 13 percent Holzworth type 3 for the winter season. No morning inversions had a base height greater than 2000 meters. Without regard to height, the most common morning thickness was near zero to 250 meters, with 90 percent for the summer season, 79 percent for the autumn season, and 82 percent for the winter season. For all months, less than 4 percent of the inversions were greater than 500 meters thick, and less than 5 percent of the inversions were Holzworth type 4 and only the summer season had Holzworth type 5 (1.3 percent).

The largest occurrence of morning inversions for both the summer and autumn seasons were surface based and 100 to 250 meters thick. Both seasons were Holzworth type 3 (summer 10 percent, autumn 7 percent). The largest occurrence of morning inversions for the winter season were based at 500 to 750 meters thick, Holzworth type 2 (6.5 percent).

Without regard to thickness, 52 percent of the summer afternoon base heights were 1000 to 2000 meters. Of these 48 percent were Holzworth type 1. Forty-four percent of the autumn season afternoon inversions were based at 100 to 500 meters--14 percent Holzworth type 2. Forty-one percent of the winter season inversions had base heights of 250 to 750 meters--15 percent Holzworth type 1. Both the summer and winter seasons had inversions with base heights greater than 2000 meters. Without regard to height, the most common afternoon thickness was near zero to 250 meters, with 96 percent for

the summer season, 93 percent for the autumn season, and 91 percent for the winter season. For all months, less than 2 percent of the afternoon inversions were greater than 500 meters thick. Only the autumn season had Holzworth type 4 and 5 (5.4 percent).

The largest occurrence of afternoon inversions for the summer season were based at 1500 to 2000 meters, near zero to 100 meters thick, Holzworth type 1. The autumn season had the largest occurrence based at 250 to 750 meters, near zero to 100 meters thick, Holzworth type 2. The largest occurrence for the winter season were based 250 to 500 meters, 100 to 250 meters thick, Holzworth type 2.

The acoustic radar located at the USFS Northern Forest Fire Laboratory provides a continuous record of atmospheric temperature fluctuations and the resulting very small scale air turbulence in the lower 1000 meters above the valley floor. The device sends a sound pulse vertically into the air, where layers characterized by marked temperature differences or wind fluctuations reflect it back to the transmitter-receiver, where the sound pulse is recorded. Temperature inversions in the lower 1000 meters usually are quite well portrayed by the acoustic radar. But, when superimposing the atmospheric temperature profile from the balloon temperature sondes over the acoustic radar pattern, it was found that occasionally an isothermal layer is similar in appearance to an inversion layer. In practically all cases, excepting those complicated by precipitation and frontal passages, however, the acoustic radar identifies stable layers, layers of neutral stability, and unstable layers in the lower atmosphere. Perhaps it is more correct to think of the acoustic radar "inversion" depiction as "stable layer" depiction.

The acoustic radar data were evaluated in two-hour time increments and

were portrayed in stability categories (Gelhaus, 1979b). The final stability classifications include acoustic radar stability interpretations in three categories: stable, neutral and unstable, and the effect of surface wind speed, cloud cover, and the sun's zenith angle (these last three parameters taken from records of the National Weather Service Airport Station, about one mile East of the radar site). Six categories, A through F, describe the two-hourly stability, with A representing the most unstable condition and F the most stable. By seasons, the percent frequency of categories shows 1 percent in categories A through C for winter, 23 percent for spring, 31 percent summer, and 13 percent autumn. The two most stable categories, E and F, occurred with 67 percent frequency in winter, 41 percent spring, 39 percent summer and 57 percent autumn.

One of the primary advantages of the acoustic radar's continuous record of low-level atmospheric stability is the ability to show times of onset and breakup of inversion or stable layers. During the winter months, especially when the ground is snow covered, a surface-based inversion or stable layer usually persists throughout the day, interrupted only by wind and atmospheric mixing accompanying winter storms or frontal passages. Excepting the winter season, surface-based inversions that form during the evening and night usually start to dissipate or lift from the surface with the advent of sufficient heat from the sun a couple of hour after sunrise. In 1978 the average time of formation of evening inversion ranged from about 1800 MST in late autumn to about 2030 MST in early summer. The lifting or dissipation process in the morning started at times as early as 0630 MST in early summer to as late as about 0930 MST in late autumn.

The rate at which the early morning inversion lifts or is dissipated from the surface upwards, can serve as a useful indicator of the amount of time that the earth's surface might be fumigated with high concentrations of air pollution trapped in the inversion layer. During the spring and summer months, the average lifting or dissipation height in the two-hour period after it begins is about 225 meters, while the fall months average only 165 meters. The lifting or dissipation process is so infrequent in winter that meaningful averages cannot be determined.

A review of low-level inversions or stable layers and their occurrence in six-hour time periods as interpreted from acoustic radar records showed marked seasonal variation. For the calendar year 1978 about 80 percent of low-level inversions appearing on the acoustic radar were surface-based. During the two six-hour periods from 1800 to 0600 MST, surface-based inversions were present 83 percent of the time, with the lowest frequency 68 percent in April and the highest 94 percent in July. During the six-hour period from 1200 to 1800 MST, when the atmosphere is most active and unstable, surface-based inversions persisted 60 percent of the time in the winter (December-February) but were entirely non-existent, 0 percent during the summer (June-August) period.

Kalispell

Surface Meteorology

Surface wind data was assessed individually at six sites in the Flathead River Basin (see Table 2).

The Polebridge site was located at the Polebridge Ranger Station just inside Glacier National Park. It was in operation only from September 1978

through November 1978. This site showed a bimodal wind direction frequency. The wind blew from the north-northeast to northeast 33 percent of the time at a light velocity of 0.5 meters per second (m/sec). This was probably a nocturnal drainage wind down the valley. The other maximum occurred between the south-southwest and west-southwest. The wind blew from this direction 32 percent of the time at a speed of 1.5 m/sec. The least common wind direction was from the east-southeast through the south-southeast where the wind blew less than one percent of the time. Calm conditions were noted here about two percent of the time. It was found that the Ranger Station proved to be a poor site location, as it was too close to the main channel of the North Fork of the Flathead River to give a fair distribution of wind directions. The main channel of the river ran on a line southwest from the site, thus the wind direction maximum from the southwest quadrant. There also proved to be too many tall trees and buildings in the vicinity of the instrument. Strong winds were dampened which resulted in the generally light winds that were recorded at this site.

The Polebridge site was moved two miles north to Big Prairie. The recorder was in operation here for one month from November 1978 through December 1978. The site was then shut down due to severe winter weather. The Big Prairie location showed wind patterns that were similar to the Ranger Station except that the wind speeds were greater. The primary maximum occurred from the north through the northeast direction. The wind blew from these directions 55 percent of the time at a velocity of about 1 m/sec. This was probably a nocturnal drainage wind down the valley. The secondary maximum was from the south to southwest (23 percent) at a velocity of 2.7 m/sec. Another significant wind direction was west-northwest through north-northwest

(11 percent) at a velocity of 2.5 m/sec. The least common wind direction was east-southeast to south-southeast (4 percent) at a velocity of about one m/sec. Calm conditions were never observed here.

The Teakettle Mountain site is located about two miles north of Columbia Falls, and about one mile north of the Anaconda Aluminum Company. Data has been recovered here from January 1978 through April 1979. This site is located in a small side valley that drains into the Flathead Valley. It shows a significant diurnal mountain valley wind system that is most notable in the spring and least apparent in the winter. During the nighttime the winds blew down the valley from the northwest to the north (41 percent annually) at an average annual velocity of 2.1 m/sec. During the daylight hours, generally starting several hours after sunrise, the winds blew up the valley from the south-southeast through the southwest (27 percent annually) at an average annual velocity of 2.6 m/sec. This event is most dramatic in the spring months when the wind speeds are greatest and the directional wind shift is the most distinct. In the spring it was found that the winds blew from the northwest through north direction 35.5 percent of the time at an average velocity of 2.7 m/sec. and the wind blew from the south-southeast through the southwest direction 31 percent of the time at an average velocity of 3.1 m/sec. The greatest wind speeds were noted from the northeast through the east-southeast (14.6 percent annually) at an average annual velocity of 5.4 m/sec. The least common wind directions were: east-southeast (2 percent annually), southeast (3 percent annually), and west-southwest (2.5 percent annually). Calm conditions were almost never observed here.

The Brant site was located in a vacant field just south of Glacier Park International Airport. It was in operation from March 1978 through May

1978, and its data represents springtime conditions. The most frequent wind direction was from the south (21.1 percent) at 1.5 m/sec. This reflects the lake effect at this time of the year. Essentially, the lake effect is an onshore wind which blows during the afternoon hours and reverses to an offshore wind during the evening. The least frequent wind directions were from the east-northeast to southeast (3.5 percent) at velocities that were generally less than 1.0 m/sec. Basically there was an even distribution of wind directions between the west-southwest and the north-northwest at about 5 percent for each of these directions. Other predominant wind directions were as follows: north (10.8 percent), north-northeast (11.6 percent), northeast (8.2 percent), south-southwest (7.4 percent) and the southwest (9.1 percent). For the most part, wind velocities were light at the Brant site. The greatest wind speed was from the north-northeast at an average of 2.0 m/sec. Calm conditions were noted here 1.4 percent of the time.

The Brant site was moved 200 yards north to the current Airport site which is located adjacent to the parking lot at Glacier Park International Airport. Data has been collected here from June 1978 to the present time. The most common wind directions were from the south-southeast (11.5 percent annually), and the south (12.4 percent annually). These wind directions were most notable in the summertime when they were observed 10.2 percent and 21.8 percent of the time respectively at velocities of 3.1 m/sec and 2.8 m/sec. This reflects the lake effect that is noticeable at this location during the spring and summer. During the afternoon hours brisk winds blow from the south off the lake. The least common wind directions were from the east-northeast through the east-southeast (4.6 percent annually) at an average

annual velocity of 1.2 m/sec. Generally winds from the south-southwest through the north were evenly distributed with a frequency of about 6 percent annually and an average annual velocity of 1.5 m/sec. The strongest winds were from the north-northeast (10.7 percent annually) at an average annual velocity of 4.1 m/sec. As a rule winds here were lightest during the nighttime and strongest during the daylight hours. Calm conditions were almost never observed here.

Data collected by the National Weather Service at Glacier Park International Airport for the months May 1978 through February 1979 has been included in this report. The NWS method of data collection varies significantly from that collected from the other wind sites used by the Air Quality Bureau in the Flathead Basin Study. First, the National Weather Service data is composed of observations made every three hours. The data recorded is exactly the particular wind direction and the wind speed at the time of observation. The Air Quality Bureau data recorded gives the average wind speed and the prevailing wind direction over an hour period of time. This makes for more calm conditions by the National Weather Service method as compared to the method used by the Air Quality Bureau. Also, the wind speed indicator used by the National Weather Service records as zero any wind speed less than 1.5 m/sec. Generally the distribution of wind directions agrees very closely to that recorded at the Airport site. The major difference is that calm conditions were more frequent in the National Weather Service data (36.7 percent annually) as compared to the Air Quality Bureau data taken at the Airport site (0.4 percent annually). These calm conditions, almost without exception, occurred during the nighttime and early morning hours.

The Geis site was located two miles south of Columbia Falls, a short distance to the east of Highway 35. Data used for this report covers the period from January 1978 through May 1978. Two wind direction maxima were observed at this location, one being from the north-northwest to north (25.5 percent) at an average velocity of 2.1 m/sec, and the other being from the south-southeast to south-southwest (37.7 percent) at an average velocity of 4.1 m/sec. The wind frequency was evenly distributed between the directions southwest to northwest at about 4 percent to 5 percent for each direction and an average wind speed of about two m/sec for each direction. The least common wind directions were from the northeast through the southeast. All of them were less than two percent annually. Calm conditions were never observed here.

The Polson site is located about one mile east of the city of Polson close to the intersection of Highway 93 and Highway 35. Data collection began there in October 1978 and has continued up to the present time. One dominant wind direction maximum occurs from the south through the southwest (61.1 percent). This also constitutes the highest wind speed averaging 2.8 m/sec. Another secondary maximum occurs between the north to north-northeast (11.1 percent) at wind velocities of 1.4 m/sec. The least common wind direction was from the east-southeast through the south-southeast (4.0 percent) at light velocities of about 1.0 m/sec. All the other wind directions occurred from between 2 to 4 percent of the time.

Although each of these wind sites are separated by considerable distances, all of them show similar distributions of wind directions. Basically, two maxima occur, one from the north and the other from the south. The primary reason for this is that the axis of each of the valleys in which the sites are

located in runs basically on a north-south line. The least common winds were from the east through the southeast. Probably the steep mountain barriers that form the eastern boundary for each of these valleys influences this. Wind directions from the southwest through the northwest are generally evenly distributed.

Strong northeast winds are indicated at both the Airport site and at the Teakettle Mountain site. These winds can sometimes be very strong averaging as much as 17 m/sec. This type of wind does not seem to be as significant in the Polebridge and Polson areas.

It would appear that Flathead Lake affects the winds at both the Airport location and at Polson. Gusty winds from the south are noticeable during the afternoon hours at the airport. They average between 2.5 to 3.0 m/sec but sometimes they can be as high as 9.0 meters per second. This phenomenon begins in late March and continues through September. The Polson data presented in this report covers the autumn and winter months. The Flathead Lake would tend to be a warm surface at this time of year and should act as a drain for surface winds. This is substantiated somewhat by the dominant wind direction from the south as observed here.

Upper Air Meteorology

The lowest inversion frequency (inversion nearest the surface) tables, derived from acoustic radar records, indicate for July and August a ground based inversion was present from 1800 MST till 0600 MST, 91 percent of the time. Typically, its depth was from 200 to 300 meters. The daylight hours from 0600 MST to 1800 MST showed no ground based inversions for these same months. In October for the hours 1800 MST till 0600 MST a ground based inversion was present 97 percent of the time. Typically its depth was 400

meters. The ground based inversion persisted longer into the morning hours in October than in the summer months. A surface based inversion was present 74 percent of the time between 0600 MST and 1200 MST in October. No ground based inversion was present from 1200 MST till 1800 MST in October. The first inversion frequency tables as prepared from the acoustic radar data for the winter months of November through February did not show this diurnal trend regarding surface based inversions so strongly. Ground based inversions were as frequent during the nighttime hours, and when they did occur they were more apt to persist through the afternoon hours. For these winter months ground based inversions were present 80 percent of the time for the hours 1800 MST till 0600 MST at a typical thickness of 300 meters. The winter months were found to have a ground based inversion present 70 percent of the time from 0600 MST till 1200 MST, and 36 percent of the time from 1200 MST till 1800 MST. In general, a ground based inversion from 100 to 400 meters in thickness, most typically about 300 meters, can be expected in the Flathead Valley through the nighttime hours into the early morning throughout the year. The summer, autumn and spring months (March through October) show a markedly diurnal pattern with a surface based inversion always present at night, with no surface based inversion present in the afternoon. The winter shows a pattern that is less dependent upon the time of day.

Elevated inversions in July and August, for the most part, are merely the extension in time of surface based inversions that formed during the night and have their bases elevated because of heating from the sun. Twenty-three elevated inversions were observed for the hours 0600 MST till 1200 MST for these summer months, all of them with bases at less than 200 meters. Notably elevated inversions can persist into the hours of maximum daylight heating even in the summer months in the Flathead Valley. Two were observed in July with bases of 300 and 400 meters. In October elevated inversions with base

substantially above the surface were observed about 15 percent of the time for all times of the day. Their bases were typically 300 to 400 meters above the ground. Many of these were second inversions above the surface based inversion. The winter months (November through February) showed more elevated second inversions than during the other seasons of the year. They were present about 12 percent of the time at a typical base height of between 300 and 500 meters.

Analysis as to the frequency and degree of stability was made using the acoustic radar data together with the cloud base height, the cloud cover, and the wind speed provided by the National Weather Service at Glacier Park International Airport. The stabilities were determined for two-hour periods continuously for the months July and August 1978, and October 1978 through February 1979. During the summer months the greatest percentage of hours are in the categories of neutral to moderately unstable. The winter months are dominated by neutral and slightly stable conditions.

Pilot balloon launches were conducted six times per week at the airport. The morning launches were one-half hour after sunrise, while the afternoon launches were taken at 1400 MST, the approximate hour of maximum heating. Upper level winds were derived from these launches up to a height of 2000 meters. The surface winds presented here are those observed at the instant of the balloon launch. The data presented in this discussion is for the period starting June 1978, and extending through March 1979.

The morning surface winds and those at 100 meters showed a distinct bimodal distribution. About 50 percent of the time the winds were from the north-northwest to east-northeast direction, and about 36 percent of the time they were from the southeast to southwest direction. This group from the

south tended to be the strongest averaging 2 to 4 m/sec at the surface and 4 to 6 m/sec at 100 meters. The morning 500 meter level shows most of the winds from the south-southeast through southwest direction (50 percent) at a speed of about 6 to 9 m/sec. At 1000 meters the majority of the winds were from the south-southwest through the west (57 percent) at an average velocity of 7.2 meters per second. At 2000 meters the wind blew from the west-southwest to northwest 71 percent of the time at an average velocity of 9.0 m/sec. As a rule there is veering of the wind direction with height between the 500 meter level and the 2000 meter level in the morning; that is, the winds tend to rotate clockwise with height. Also the wind speeds increase with height. The average morning wind speeds were as follows: surface- 1.9 m/sec; 100 meters - 4.5 m/sec; 500 meters - 5.1 m/sec; 1000 meters - 7.1 m/sec; and 2000 meters - 8.9 m/sec.

The afternoon pilot balloon launches showed a uniform wind direction maximum from the south-southeast through the south-southwest at 53 percent of the time between the surface and the 500 meter level. These also represented the strongest winds averaging 3.1 m/sec at the surface, 4.0 m/sec at 100 meters, and 6.5 m/sec at 500 meters. Again, there is a slight veering in the prevailing wind direction between 500 and 2000 meters. At 1000 meters the predominant wind direction is from the south to the west about 63 percent of the time at a velocity of between 4 to 6 m/sec. At 2000 meters the prevailing winds are from the west-southwest to the northwest (70.5 percent) at a velocity averaging 7.7 m/sec. The distribution of wind directions in the afternoon and the morning agree almost perfectly at the 2000 meter level.

During the summer months, June through August, it was found from the morning upper level winds that about 50 percent of the time a directional

wind shift occurred between the lower levels (surface to 300 meters), and the 750 meter level. The lower level winds were from the north and light, and the winds at 750 meters were primarily from the south.

The inversion frequency of occurrence tables are based on data derived from temperature sondes that were launched along with the pilot balloons. These inversions are also classified using the Holzworth system which has type 1 as the least stable and type 5 as the most stable. The information presented in this discussion includes the period from July 1978 through February 1979.

In the summer months of July and August surface based inversions were present 67 percent of the time. Most inversions had a thickness of less than 300 meters, and a large number of inversions occurred with a base height of between 250 and 750 meters. These were mostly of Holzworth classification between 1 and 3. Most inversions that occurred had a thickness of less than 250 meters.

Summer afternoon temperature sonde traces showed no inversion 76 percent of the time, and no surface based inversions at all. Those that did occur were generally less than 250 meters thick and fell into the Holzworth classifications of 1 and 2.

The autumn morning data shows surface based inversions present 65 percent of the time. Half of these were of Holzworth classification 4. Seven had a thickness that was greater than 250 meters. The autumn inversions were generally thicker and more stable than those in the summer. In similarity with the summer there appeared a large number of elevated inversions with a base height of between 251 and 750 meters. These were mostly of Holzworth type 1 through 3. Most inversions that were not ground based had a thickness of

IV. SUMMARY

An analysis of the meteorological data collected under the first year of MAPS and other coincident studies has been made. Analyses dealt primarily with the meteorological variables related to air pollution potential. No attempt was made to relate the meteorology to air quality or health effects, as this was not the purpose of this report.

Data on the surface and upper level winds in the various study areas has revealed predominant wind patterns for the various months and seasons sampled. Inversion data from two measurement methods was summarized and comparisons made as to frequency of occurrence of various inversion parameters such as thickness, height, intensity, and duration. Stability data derived from acoustic radar data, cloud data, and wind speed was also tabulated continuously in two-hour periods.

At the time this report was being written, a second year of meteorological monitoring was beginning. A final report encompassing the entire data collection period is anticipated. It is hoped that data not included in this report could be analyzed for the final report in 1980.

REFERENCES

- Holzworth, G. C., 1974: Climatological Data on Atmospheric Stability in the United States. American Meteorological Soc. Sym. on Atmos. Diff. and Air Pollution.
- Gelhaus, J. W., et al., 1979a: Meteorological Study Columbia Falls, Montana. Air Quality Bureau, Montana Department of Health and Environmental Sciences, Helena, Montana.
- Gelhaus, J. W. et al., 1979b: Montana Air Resources Modeling System. Air Quality Bureau, Montana Department of Health and Environmental Sciences, Helena, Montana.

